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NO_x Removal of Pervious Concrete Pavement Materials with TiO_2 †

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Abstract: Various studies have been conducted on reducing NO_x emissions; titanium dioxide (TiO_2) is widely used to reduce NO_x in the air. This study proposes a method for exploiting the advantages of photocatalytic technology and water permeability to reduce NO_x emissions. The study comprises porosity, water permeability coefficient, compressive strength, and NO_x removal experiments. Based on the experiments, an optimum mix proportion is suggested. The results revealed that the NO_x removal effect is greater for variables with higher porosity. The removal is further enhanced by the use of siloxane, which hardens the surface of the TiO_2-incorporated cementitious materials in the mixture.

Keywords: NO_x removal; TiO_2; pervious concrete; pavement; permeability; porosity

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1. Introduction

Over the past decade, the number of torrential rain events in Korea has increased approximately 1.5 times compared to the past, and the frequency of these events has increased six times [1]. Increases in phenomena such as heavy rainfall are closely related to climate change. Compared to the past, the annual average temperature reached its peak in 2016, confirming that global warming is continuing [2]. The main cause of these phenomena is air pollution caused by emissions of large amounts of substances such as fine dust, nitrogen oxides (NO_x), and carbon dioxide [3]. More than 50% of total NO_x emissions are caused by automobiles. Thus, reducing automobile usage can lead to reduced NO_x emissions; however, that is almost impossible to achieve because of increasing numbers of advance automobiles. Therefore, the development of structures such as a NOx absorbing infrastructure is necessary for reducing NO_x emissions. Various studies have been conducted worldwide to reduce NO_x emissions, and one of the most widely used materials in the construction field is titanium dioxide (TiO_2) [4]. TiO_2 is a photocatalytic material that can adsorb NO_x. To exploit this property, we sought to develop pervious concrete that can adsorb NO_x over a larger area.

Accordingly, as basic research for the development of photocatalytic pervious concrete to reduce NO_x, this study aims to evaluate the basic physical properties of pervious concrete, such as porosity, permeability coefficient, and compressive strength. Moreover, we intend to conduct experiments on the NO_x removal ratio to analyze the NO_x reduction effect according to two types of photocatalysts, namely, TiO_2 and spray-type.

2. Material and Methods

2.1. Materials

Type I (equivalent to Type I) Ordinary Portland cement, coarse aggregates with a maximum size of 10 mm, TiO_2, isopropyl alcohol (IPA) solution with a specific gravity of 0.79 was used. Properties of aggregates and TiO_2 are listed in Tables 1 and 2, respectively.

Table 1. Physical properties of aggregates with a maximum size of 10 mm.

Aggregate Size	Specific Gravity	Absorption Rate	Fineness Modulus
10 mm	2.6	1.9%	5.9

Table 2. Properties of TiO_2 used.

Type	Specific Gravity	Content	Particle Size	Molecular Weight
anatase	4.0	98.5%	0.35–0.5 µm	77.9 g

2.2. Experimental Details

2.2.1. Mix Proportion

The mix proportions used in this study are listed in Table 3. TiO_2 was incorporated by substituting 5% and 10% of cement weight.

Table 3. Mix proportions used.

Variable	W	C	TiO_2	G	[1] S/P
OPC	108	360	-	1814	0.9
T5		342	18	1817	
T10		324	36	1820	

[1] S/P: superplasticizer added 0.25% binder weight to volume.

2.2.2. Porosity Measurement Method

The porosity of the pervious concrete was measured using the porosity test method suggested by the Concrete Research Committee of the Japan Concrete Institute (JCI). Equations (1) and (2) are used to measure the total and continuous porosities, respectively.

$$Total\ Porosity = \left(1 - \frac{W_2 - W_1}{V}\right) \times 100, \quad (1)$$

where, W_1 is the weight of the specimen in water; W_2 is the weight of the specimen in an absolutely dry state; and V is the specimen volume.

$$Continous\ Porosity = \left(1 - \frac{W_2 - W_1}{V}\right) \times 100, \quad (2)$$

2.2.3. Permeability Coefficient-Measurement Method

Because the permeability coefficient of pervious concrete is more than 105 times larger than that of ordinary concrete, it is impossible to measure the permeability coefficient using the permeability method for ordinary concrete. Therefore, we measured the permeability coefficient according to ASTM C 1701 "Standard Method for Infiltration Rate of In Place Pervious Concrete" using Equation (3).

$$I = \frac{K \times M}{D^2 \times t}, \quad (3)$$

where, I denotes the infiltrate in/h; M denotes mass of infiltrated water (lb); D denotes the inside diameter of the infiltration ring (in); t denotes the time required for the measured amount of water to infiltrate the concrete (s); and k = 126,870 (constant).

2.2.4. Compressive Strength Measurement Method

Using a Φ100 × 200 mm cylindrical mold, the compressive strength was measured after 28 days according to KS F 2405.

2.2.5. NO_x Removal Ratio Test Method

The NO_x removal ratio test was conducted according to KS L ISO 22197-1. The test was conducted by supplying a mixed gas with a certain concentration of nitric oxide and high-purity air at a certain ratio, while emitting ultraviolet light to activate TiO_2, which adsorbs NO_x when exposed to light.

2.2.6. TiO_2 vs. Spray-Type Photocatalyst Test Method

To compare the NO_x removal effect of pervious concrete using TiO_2, the specimens with dimensions of 100 mm × 100 mm × 400 mm, height, breadth and length, respectively, were used. A spray-type photocatalyst was sprayed on the pervious concrete to create a test specimen for comparison. A comparison of the NO_x removal ratios between the TiO_2-substituted and photocatalyst-sprayed specimens was conducted using the same process as the removal ratio test method described in Section 2.2.5.

3. Experimental Results and Analysis

3.1. Basic Property Evaluation

Table 4 presents the experimental results for evaluating the basic properties, including the porosity, permeability coefficient, and compressive strength. The continuous porosity of all the variables was approximately 7%, and the permeability coefficients were similar.

Table 4. Results of basic property evaluation experiments.

Variable	Compressive Strength (MPa)	Total Porosity (%)	Continuous Porosity (%)	Permeability Coefficient (cm/s)
OPC	17	9.30	7.60	1.25
T5	18.3	9.00	7.02	1.22
T10	18.0	8.90	6.89	1.20
T5-IPA	18.3	8.90	7.00	1.20
T10-IPA	18.4	8.80	6.84	1.19

3.2. NO_x Removal Ratio Test Results

Table 5 presents the NO_x removal ratio and total porosity results. For the OPC without photocatalysts, the NO_x removal ratio was 0.2%, indicating almost no removal effect. However, the removal ratios for the 5% and 10% TiO_2 substitution samples were 49% and 37%, respectively, indicating excellent NO_x removal. The removal ratio was expected to increase as the TiO_2 substitution rate increased; however, the experimental results were inconsistent with this expectation.

Table 5. NO_x removal ratio and total porosity.

Variable	Total Porosity (%)	Removal Ratio (%)
OPC	9.30	0.2
T5	9.00	49.0
T10	8.90	37.0
T5-IPA	8.90	35.1
T10-IPA	8.80	27.7

4. Conclusions

This study evaluated the basic properties of pervious concrete, including porosity, permeability coefficient, and compressive strength, and conducted experiments on the NO_x removal ratio by using TiO_2 and spray-type photocatalysts. The conclusions are as follows.

According to the NO_x removal ratio test results for pervious concrete with TiO_2, the 5% substitution variable showed a better removal ratio than the 10% substitution variable. Thus, we conclude that the best NOx removal ratio can be achieved with an appropriate mix proportion of TiO_2, rather than based on the amount of TiO_2. Therefore, further experimental research on the optimal mixing proportion of TiO_2 is necessary.

TiO_2 was applied to pervious concrete with a large air-exposure area to increase the NO_x removal ratio. However, pervious concrete formed a somewhat high porosity, which made it difficult to apply TiO_2 to concrete structures such as road pavements and parking lot decks. Therefore, additional evaluations of the durability characteristics should be conducted along with evaluations of the mechanical performance because of the high porosity.

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References

1. Kim, Y.T.; Park, M.Y.; Kwon, H.H. Spatio-Temporal Summer Rainfall Pattern in 2020 from a Rainfall Frequency Perspective. *Korean Soc. Disaster Secur.* **2020**, *13*, 93–104.
2. *Korean Climate Change Assessment Report 2020*; Korea Meteorological Administration: Seoul, Korea, 2020; ISBN 978-89-954715-8-6.
3. Kwon, W.T. Current Status and Perspectives of Climate Change Sciences. *Asia-Pac. J. Atmos. Sci.* **2005**, *41*, 325–336.
4. Seo, J.H.; Yoon, H.N.; Kim, S.H.; Bae, S.J.; Jang, D.I.; Kil, T.G.; Park, S.M.; Lee, H.K. An Overview on the Physicochemical Properties and Photocatalytic Pollutant Removal Performances of TiO_2-incorporated Cementitious Composites. *Compos. Res.* **2020**, *33*, 68–75.